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WHAT IS THE UNIVERSE, AND WHY IS IT DOING THESE STRANGE THINGS?

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1979 marks the fiftieth anniversary of a major advance in man's attempt to understand the overall structure of the physical universe. It was in 1929 that Hubble announced his discovery of the expansion of the universe. Ever since that time, astronomers have been finding evidence that the entire universe has been evolving, and have been attempting to adjust their view of the world accordingly. If the expansion which Hubble discovered is extrapolated back in time, we come in imagination to an epoch when all the matter which we now observe would have been squeezed into a volume less than that of a present-day atomic nucleus. Can such a fantastic extrapolation really make sense? If not, we may have reached a limit of scientific understanding. However, it is possible that the known laws of physics *can* be used to understand the very early universe, and that we can win a better understanding of why the universe is as it is.

Attempts to understand the structure of the universe did not, of course, begin with Hubble. When Galileo turned his first crude telescopes on the Milky Way, he found it to consist of a vast number of stars, too distant to be seen separately with the naked eye. The shape of this broad band of stars suggests that we are within a large, disc-shaped distribution of stars, gas and dust. It was not until the early part of this century that the full extent of our *galaxy* became known: the galactic disc is about a hundred thousand light years across, and its thickness is about a tenth that.

But is the Milky Way the entire universe? There were some astronomers who thought so sixty years ago, but others argued that some of the nebulae, or "clouds" of matter in space, were not within the Milky Way at all, and were separate galaxies in their own right. In order to resolve this dispute, it was necessary to find a way to measure the distances to these nebulae. This could be done by identifying certain types of very bright stars (with distinguishing features) in the nebulae, for a comparison of the observed luminosity of such a star and its known rate of radiation would allow its distance to be calculated. Hubble, working with the 100-inch reflector at Mount Wilson, used such distance measurements to show that many of the nebulae *were* outside our own galaxy. The Andromeda Nebula, for example, which can be seen with the naked eye as a faint, hazy patch, turns out to be more than two million light years away. Clearly our own galaxy is not the entire universe, but is one of a large number of galaxies spread throughout the universe.

Hubble's next discovery was even more revolutionary. The light from distant galaxies was found to be shifted toward the red end of the spectrum in a systematic way, the more distant galaxies showing the greatest shift. The most natural explanation of this was the *Doppler effect*, a change in the wavelength of radiation when its source is moving with respect to an observer. If the source is moving toward the observer, the waves will be "squeezed together" and shortened, while recession of the source will produce longer waves. This shift in wavelength (and thus frequency) can be detected easily with sound waves: stand beside the highway and listen to the change in pitch of a car's tires as it passes.

The lengthening of light waves from galaxies thus indicates an overall expansion of the universe: every galaxy is moving away from every other galaxy, with a velocity proportional to the distance between them. This behavior can be accounted for with a very simple model developed by the British astrophysicist Milne. If all the galaxies had been confined to a very small region of space at some instant in the past and had then exploded, the galaxies which were travelling fastest to begin with would, by now, have traveled the farthest. The distance to each galaxy would be proportional to its velocity, which is just what Hubble found. After finding distances to galaxies and their velocities, we can calculate the time since the beginning of the expansion. This number is still uncertain because of difficulties with distance measurements, but is probably between fifteen and twenty billion years. If the gravitational attractions of the galaxies, which slow the expansion, are taken into account, this estimate must be decreased.

But is this extrapolation back to a tremendous explosion involving the entire universe the best theory? Some scientists have thought not, and have attempted to develop alternate theories, introducing, for example, the idea of continuous creation in a universe that expands forever without any overall change. However, we now have evidence that the universe was once much hotter and denser than at present. George Gamow, one of the major exponents of a *big bang* model, predicted in the 1940's that electromagnetic radiation from the big bang should still pervade the universe, and this makes possible a test of the theory, since it should be possible to detect this radiation. The temperature of matter and radiation would have been very high in the beginning, but would have dropped as the universe expanded. The wavelengths of radiation would have increased — the red shift again. Gamow and his co-workers predicted that the relic radiation from the early universe should now have a temperature of about 5°K, and wavelengths around a millimeter.

The *microwave background* was not detected until 1965, and then by accident. Penzias and Wilson discovered, from all over the sky, radio waves with a wavelength of 7.35cm. Many later observations at other wavelengths have shown that this radiation has the characteristics of radiation at a temperature of about 2.7°K. There is now general agreement that this is the radiation from the *primeval fireball*, emitted when the universe was a few hundred thousand years old.

We cannot literally "see" farther back in time than this, because radiation from earlier epochs would have been strongly scattered. However, there may still be "messages" from the early universe to be found. These might play the same role as the fossils which tell us about the early history of our planet. In the first *minutes* of the expansion of the universe, the temperature and density of matter would have been high enough for nuclear fusion reactions to take place, building up protons and neutrons into heavier atomic nuclei. Detailed calculations indicate that something on the order of 25 to 30 percent of the matter in the universe should have been converted into the most common isotope of helium. Almost all the rest would be ordinary hydrogen, with slight traces of other nuclei. Observations seem to indicate that this prediction is generally correct, though much further work needs to be done on this.

There still remain many fundamental questions — and probably always will. To answer the following questions, advances in both observational and theoretical work will be needed.

How do galaxies form, and why do different types of galaxies — spirals, ellipticals and irregulars, for example, exist? How are galaxies related to quasars, the compact objects in which highly energetic processes take place, and whose large redshifts suggest that they are at a great distance, and are being observed as they were at an early period of the universe?

Why is the universe as uniform on a large scale as it appears to be? The uniformity of the fireball radiation indicates that any large irregularities in the universe were "ironed out" at a very early epoch. What processes were responsible for this?

Is the rate at which the universal expansion is slowing down sufficient to ever make it stop, to be followed by contraction? Is the density of matter sufficient to make this occur by gravitational attraction?

The best theory we now have for construction of models of the universe, Einstein's theory of gravitation, indicates that the density of matter was infinite at the instant when the expansion began, and we cannot calculate anything before this. Does this mean a real breakdown of physical laws? This infinity can be avoided by, for example, introducing negative mass (and thus repulsive gravitation), but is such a modification reasonable? The introduction of negative masses and energies may violate the condition that cause must precede effect. We must, however, be prepared for just about anything when our theories attempt to encompass the entire universe.

Reference

The *Scientific American* articles collected in *Cosmology + 1*, ed. O. Gingerich (Freeman, San Francisco, 1977), provides a good start for further reading.

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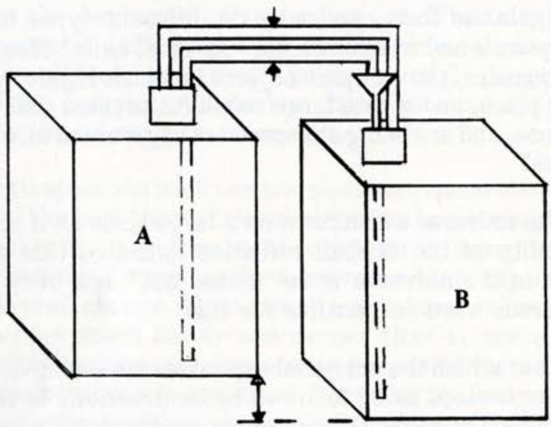
Perpetual Motion

Fig. 1 shows a device that performs almost like a perpetual motion machine. To make the device, fill can A full of water and leave can B empty. Place in stoppers and tubes as illustrated making sure the system is airtight. Note that the tubes going to and from the funnel go deep into the cans and that the air tubes do not. To start the machine, pour a beaker of water into the funnel in can B and position the cans so that can A is about 2.5 cm higher than can B. What causes the machine to run? What causes it to stop?

Science Newsletter (March 1978), North Carolina Department of Public Instruction.



Iowa Autumns

Driest Month (State Average): 0.02″ — Oct. 1952

Highest Barometric Pressure: 31.09″ — Sioux City — Dec. 29, 1917

From *Iowa's Weather* by Paul Waite.